EASTERN REGION TRAINING AND EVALUATION MODULE NO. 3
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THE IMPACT OF SEASONAL DIFFERENCES IN AIR AND SEA TEMPERATURE ON WIND SPEED FORECASTING

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This module is designed to improve land and marine wind forecasts by evaluating the impact of seasonal air and sea temperature differences on wind speed. Four basic seasonal patterns and their typical impact on wind speeds will be discussed.

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1. Objectives

Upon successful completion of this module, the reader will be able to:

> **a. List the four primary weather patterns in which land and marine wind speed forecasts are affected by seasonal air and sea temperature differences.**
>
> **b. Without reference to this Training and Evaluation Module (TEM), describe the impact of these four patterns on wind speed.**
>
> **c. Given a surface analysis from an actual event, name the seasonal pattern it represents, and make a wind forecast that improves over computer model guidance for that event.**

2. Introduction

To many meteorologists, the forecasting of wind speed is as simple as looking at the pressure gradient and/or looking at numerical model guidance. Although this approach may work a large percentage of the time (usually when wind is controlled by synoptic scale features), there are instances when applying this technique will lead forecasters to make erroneous forecasts (usually when wind is controlled by sub-synoptic scale features). These instances occur routinely throughout the course of each year, and are easily recognized once the forecaster understands the processes involved.

The goal of this module is to help forecasters improve their wind speed forecasts, which in turn will help a diverse range of users who make daily decisions based on wind forecasts. From the commercial fisherman, to the general aviation pilot, to fire weather interests, accurate wind forecasts are critical.

The remainder of this module will discuss the physical processes affecting wind speed with regard to the seasonal differences in air and sea temperature. Typical seasonal patterns will be presented along with their impacts on wind speed forecasts. In addition, conceptual surface plots of each pattern discussed (which are drawn from representative events) are shown in Figures 1 through 4. At the end of this paper you will be asked to apply the principles of this lesson to an actual operational event.

3. Training

Effects on wind speed due to differences in air and water temperature can occur at any time of the year, with each season having its own specific pattern. As air comes in contact with warmer/colder land or warmer/colder water, air mass modification occurs and results in the air mass becoming more or less stable. If the temperature difference between the air and that of the land or water is small, then its impact on wind speed will normally be small. If the difference is large, then a dramatic impact on wind speed may occur (National Weather Service 1996). This air mass modification may be dramatic enough to lead to the formation of meso- high pressure systems in areas where the air is being cooled, and the formation of meso-low pressure systems in areas where the air is being warmed (Nese et al. 1996). Synoptic scale numerical models cannot always effectively forecast sub-synoptic scale events.

An important reason for the seasonal impact on wind speed is the lag in water temperature change (and thus the lag in change of the air temperature within the marine layer) when compared to the change in air temperatures over land. This leads to colder air temperatures in the marine layer during spring and summer, with warmer marine layer air temperatures during fall and winter (when compared to air temperatures over land).

Now let's examine four seasonal patterns in the eastern United States that impact wind speed forecasting, resulting from the processes outlined above.

a. Winter Coastal Front

During the winter months coastal fronts often occur when cold high pressure is located north of a forecast area and low pressure develops south of the area (Fig. 1). The cyclonic circulation around the low brings in a strong southeast wind which is relatively mild due to marine influences. The anticyclonic circulation around the high funnels in cold and relatively dry air, and the front forms where these two circulations meet. In the example in Fig. 1, the winds are strong and gusty on the marine (warm) side of the front. **As this wind encounters the cold and more dense air over the land (or cold) side of the front, it is forced up and over the top of this cold air dome, thereby stabilizing the air mass. By looking at the pressure gradient and/or numerical guidance in this type of pattern, one is often led to believe that the entire**

forecast area will be windy when in actuality it is windy only over areas on the marine side of the front (typically from the coast to a few miles inland). Over land the strong winds are aloft, mainly affecting higher terrain. In certain regions coastal fronts may occur into the first half of spring.

b. Spring Cold Marine Layer

In spring, as air over land becomes warmer but ocean water and marine layer air temperatures remain cold, marine wind speeds are sometimes overforecast. This is especially true in the absence of precipitation, which can serve to mix winds aloft down to the surface. At this time of year, air in the marine layer is often colder than the air being transported over it (Fig. 2). The resultant difference in air density causes **winds associated with the relatively milder airmass to stay above the marine layer, again stabilizing the air mass, resulting in a loss of momentum. This can lead to lower than expected marine wind speeds**. The larger the difference in temperature between the milder air moving over the colder marine layer, the more likely it is that the winds will be lower than otherwise expected.

c. Summer Sea Breeze Front

Summer brings much warmer air temperatures over land, and to a lesser extent, to the air in the marine layer. As a result of daytime heating, the air over the land surface destabilizes and becomes increasingly buoyant as the morning progresses. As this process continues, air in the cooler, more dense, marine layer moves toward the area vacated by the rising, warm air. This is the (simplified) basis for what is known as a sea breeze, with the leading edge of the maritime air intrusion known as the sea breeze front (Fig. 3). This pattern often occurs with high pressure centered overhead or nearby, and thus little or no large scale pressure gradient exists in the area. **Numerical guidance will often forecast the wind shift that occurs with the passage of the sea breeze front, but will underforecast the strength of the wind. One factor which contributes to sea breeze strength and penetration is the difference in air temperature between the air over land compared to that of the marine layer: the greater the difference, the stronger the sea breeze**. The greatest differences usually occur in early summer when the temperature difference between land and water is a maximum (Nese et al. 1996). **Another consideration is whether a light, pre-existing onshore flow already exists before the sea breeze develops; this would also increase the strength and the inland extent of the sea breeze** (conversely, a light, pre-existing offshore flow would decrease the sea breeze intrusion). In certain areas sea breezes occur in spring and fall as well.

d. Fall Warm Marine Layer

In the fall, the opposite process of the spring cold marine layer pattern takes place. Air over land turns colder while air over water stays relatively mild; water temperatures are usually at their warmest in late summer and early fall (Fig. 4). **The colder air moving over the warmer marine layer destabilizes the air mass. This process can lead to stronger winds above the marine layer to mix down to the surface, resulting in stronger winds than expected from numerical guidance**. **Once again, the greater the difference in temperature between the two air masses, the stronger the wind can become**.

This pattern can be especially difficult to recognize at night. As the gradient relaxes, one might think that the winds over the water will diminish. However, the opposite may actually be true. This is because under a clear sky at night the land can cool rapidly while the water temperature remains relatively constant (in effect, warmer than the land). Thus, a *land* breeze may develop, adding to the strength of the wind over the water.

4. Conclusion

Seasonal land-sea temperature differences, in conjunction with certain weather patterns, can significantly affect wind speed forecasting as it relates to numerical guidance. Often changes in air mass stability, or sea or land breeze development, result from these seasonal changes. As we have seen, coastal regions may be more susceptible to the patterns described due to such dramatic temperature differences. Knowledge of the importance of the impact of these seasonal changes on wind speed will help the meteorologist improve on model guidance forecasts considerably.

REFERENCES

National Weather Service, 1996: Air-Sea Interaction. *Marine Forecaster Guide and Reference Manual*. NOAA, U.S. Department of Commerce, 636-656.

Nese, J. M., L. M. Grenci, T. W. Owen, D. J. Morningweg, 1996: *A World of Weather*. Kendall-Hunt, 514 pp.

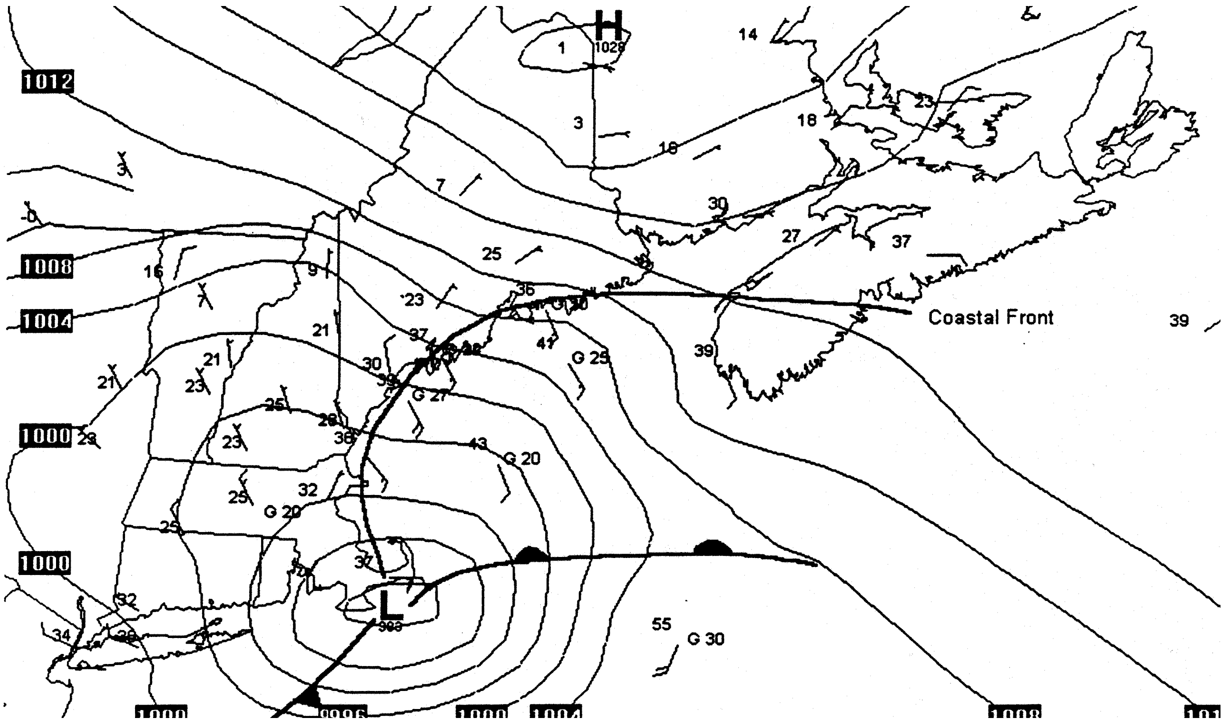

Fig 1. Conceptual surface plot of a winter coastal front. Wind barbs (kt), air temperature (° F) and wind gusts (kt), if any, are shown. Note the difference in wind speeds on each side of the coastal front.

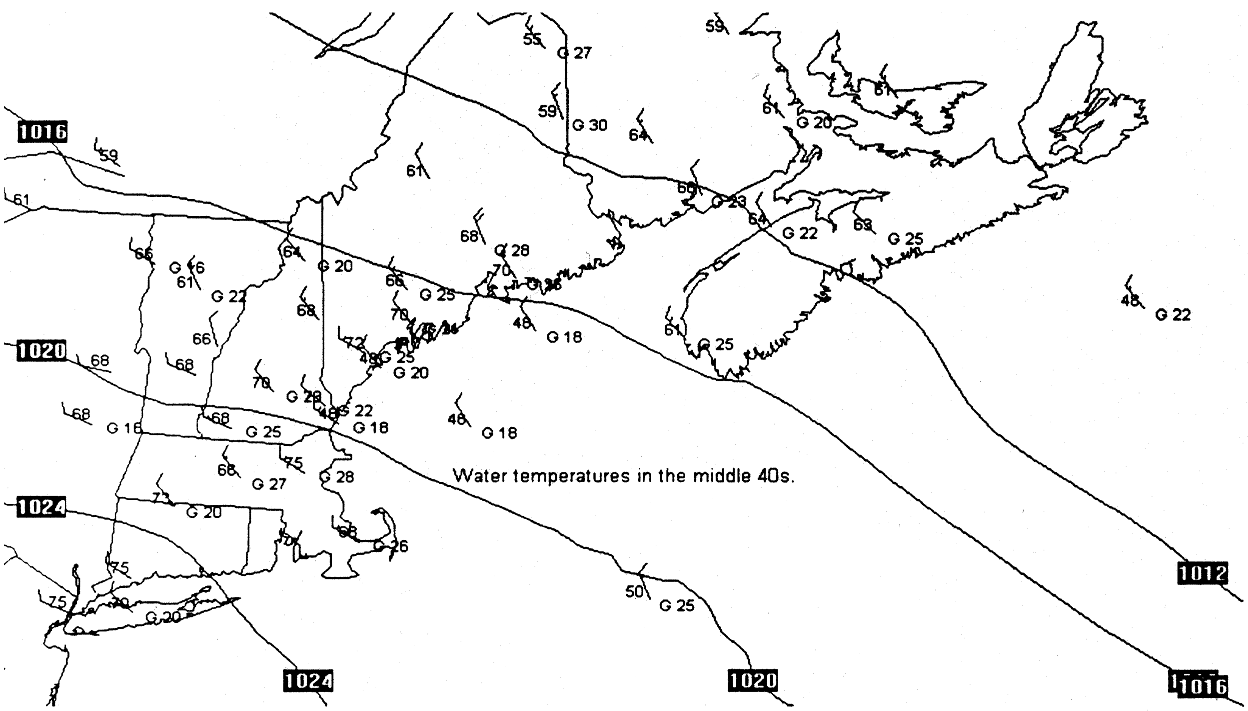

Fig. 2. Conceptual surface plot of a spring cold marine layer. Note the contrast in wind speeds between the land and sea surface.

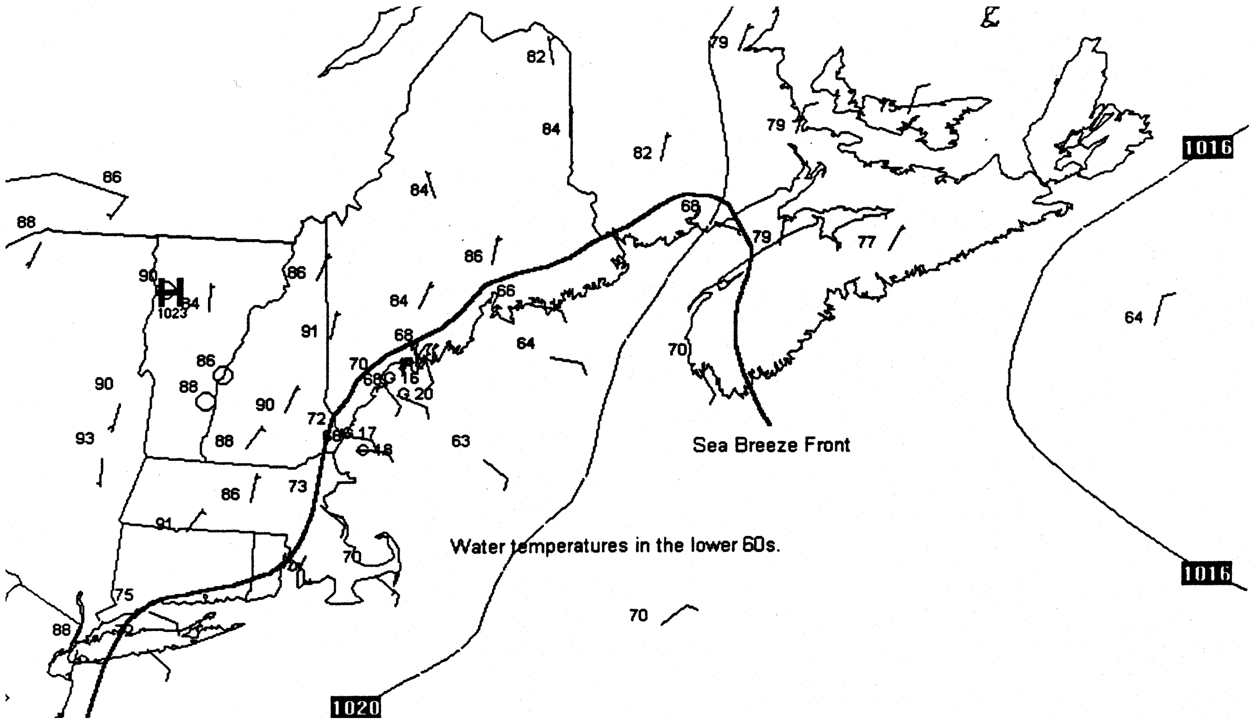

Fig. 3. Conceptual surface plot of a summer sea breeze front. Note the strength of the sea breeze
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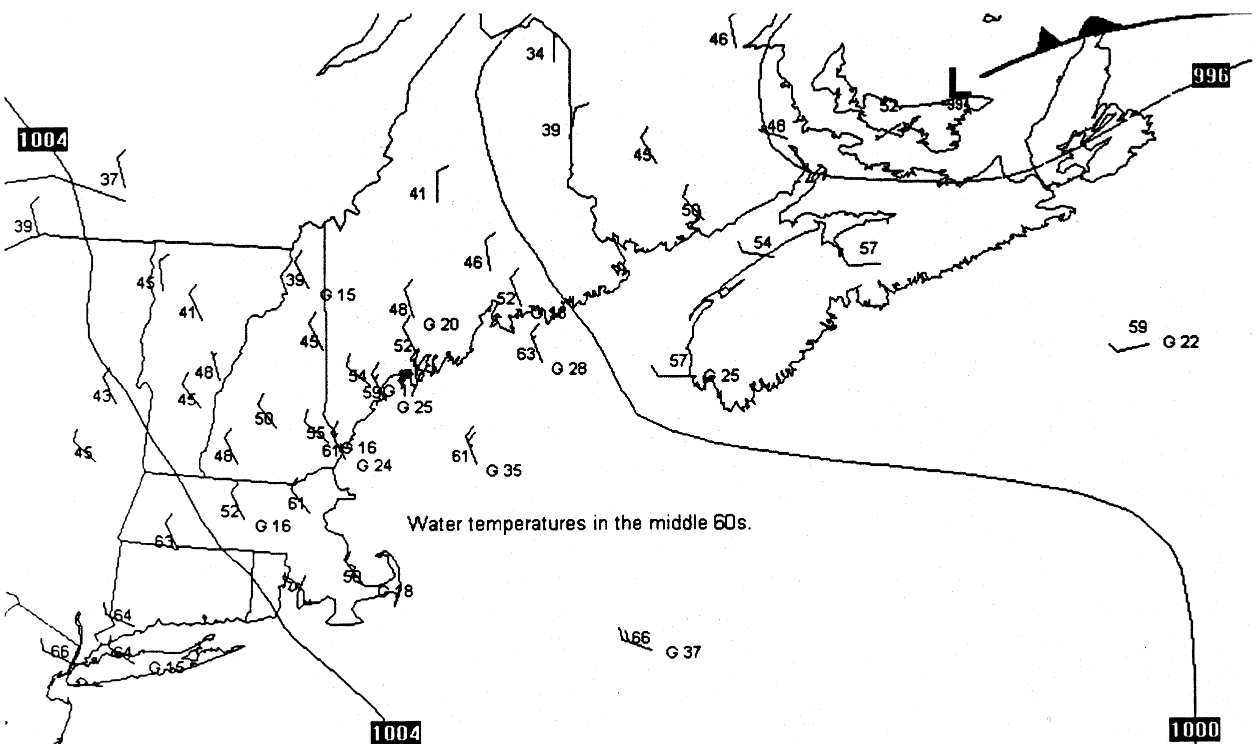

Fig. 4. Conceptual surface plot of a fall warm marine layer. Note the strength of the winds offshore.

PRACTICE

1. List the pattern that is described most accurately by each of the following statements, and give the seasons in which it most often occurs.

    a. Decreases wind speed over land (except for higher terrain) even though numerical guidance and pressure gradient analysis would suggest a windy forecast.

    b. Increases wind speed over the water, especially when winds just above the surface are strong.

    c. Decreases wind speed over water as strong winds over land advect over the marine layer.

2. What is one of the primary reasons that greater differences in temperature between the land and sea usually mean greater impact on wind speed?

3. Identify which (if any) of the four patterns described in this paper affect your forecast area. If more than one, which would have the most significant impact on wind speed, and why?

ANSWERS TO <u>PRACTICE</u> EXERCISES

1. a. Winter coastal front (winter and early spring).
   b. Fall warm marine layer (late summer and fall).
   c. Spring cold marine layer (spring and early summer).

2. 1) Significant change in the stability of the air mass, and/or 2) development of a sea or land breeze.

3. If your forecast area encompasses or borders a large body of water (such as an ocean or the Great Lakes), then you probably should have listed some or all of the wind patterns discussed. Your explanation should include the role that any local influences may have in a favoring onr or more patterns.